Krypton-85 Removal for LZ Using Gas Charcoal Chromatography

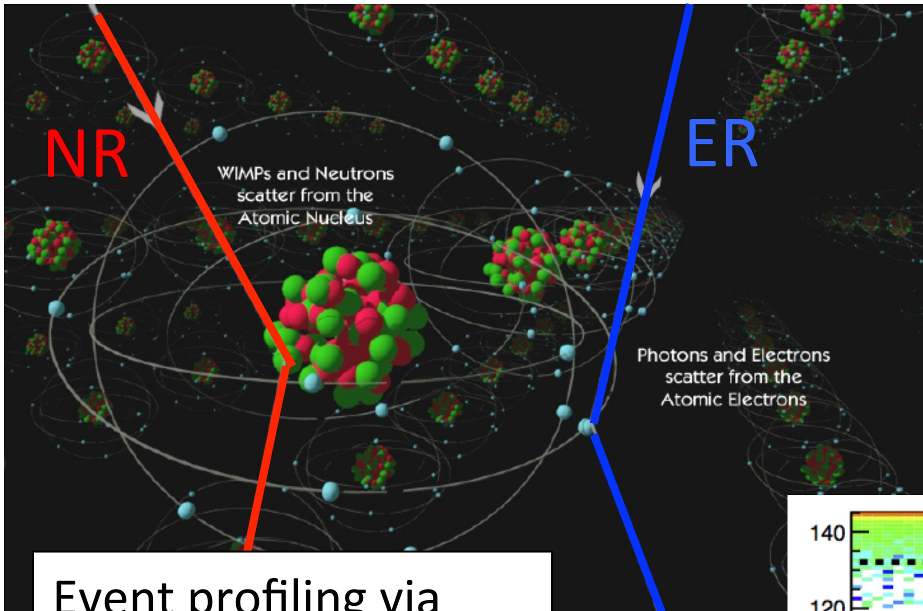
Christina Ignarra

LIDINE

September 22, 2017

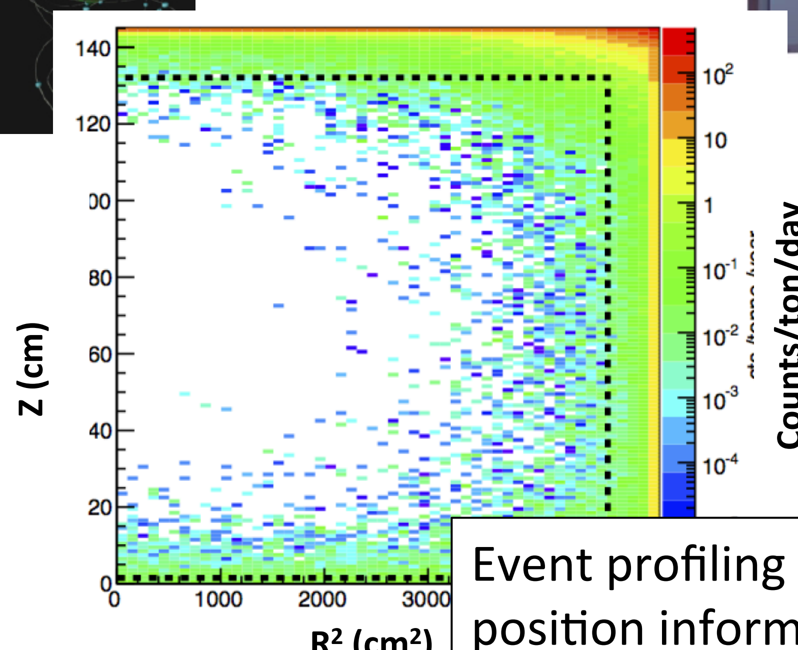
SLAC NATIONAL ACCELERATOR LABORATORY

Background Mitigation in Xe



Event profiling via charge to light ratio

Removal of electronegative impurities

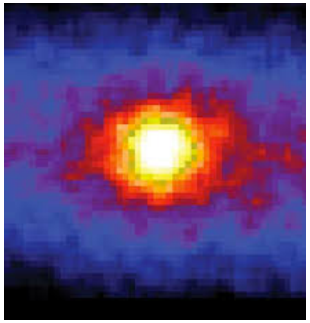


Event profiling via position information

Remaining Backgrounds in The Bulk Xenon

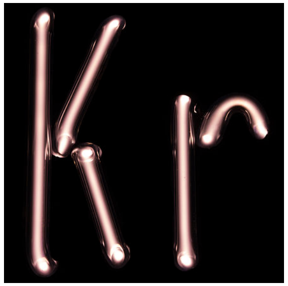
(Luckily these are ER backgrounds…)

- Solar neutrinos
  - Irreducible
  - ~1 event per day in LZ



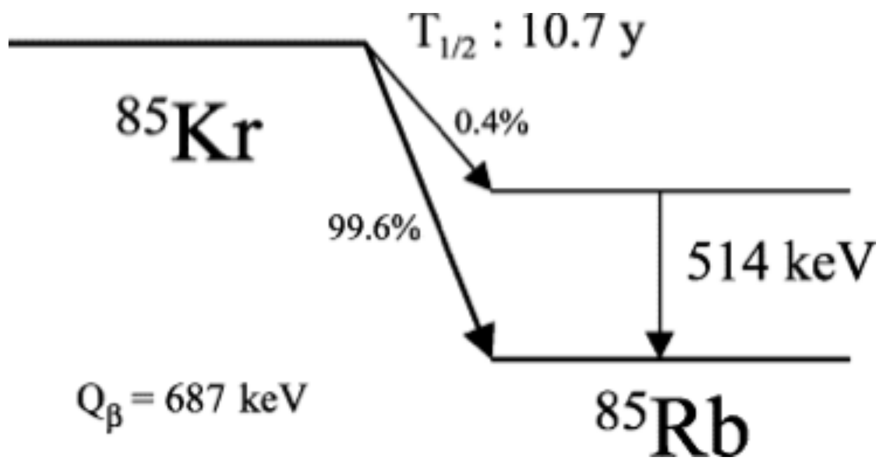
- Radon
  - Prevent during construction
  - Internal mitigation
  - Goal: 0.67 mBq

- Krypton (this talk)
  - Atmospheric gas: present in commercial Xenon at the ~10,000 ppt level
  - Goal: 0.015 ppt (corresponds to 1/10 of solar neutrino background)
  - Removed in advance



Kr-85

Kr-85 is an ER-like background (beta emitter)

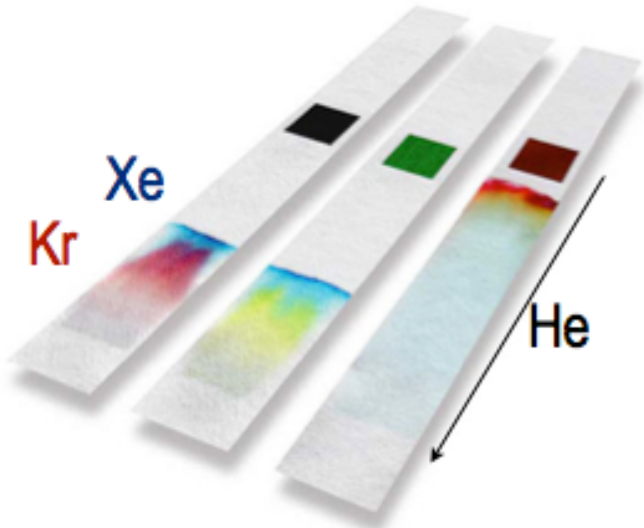


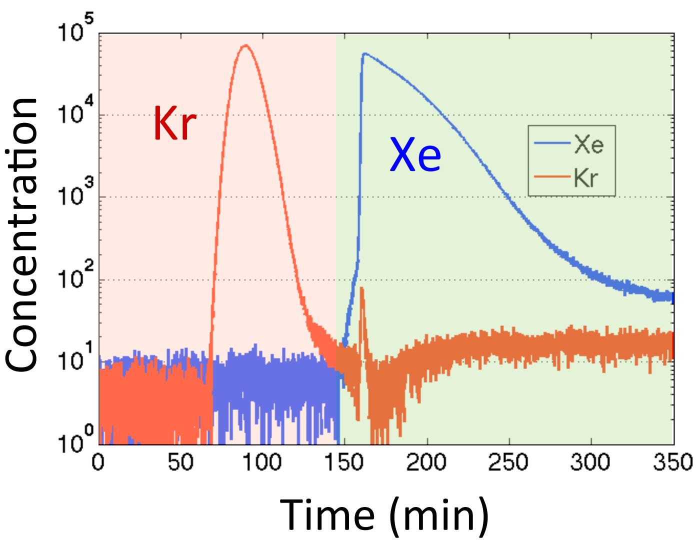
~10,000 ppt →	3 ppt →	0.015 ppt	(0.300 ppt)
Commercial Xe	LUX	LZ Goal	(LZ requirement)

- 0.015 ppt corresponds to only a shotglass of air in LZ's 10 tons of xenon
- Remove via gas charcoal chromatography

Gas Charcoal Chromatography

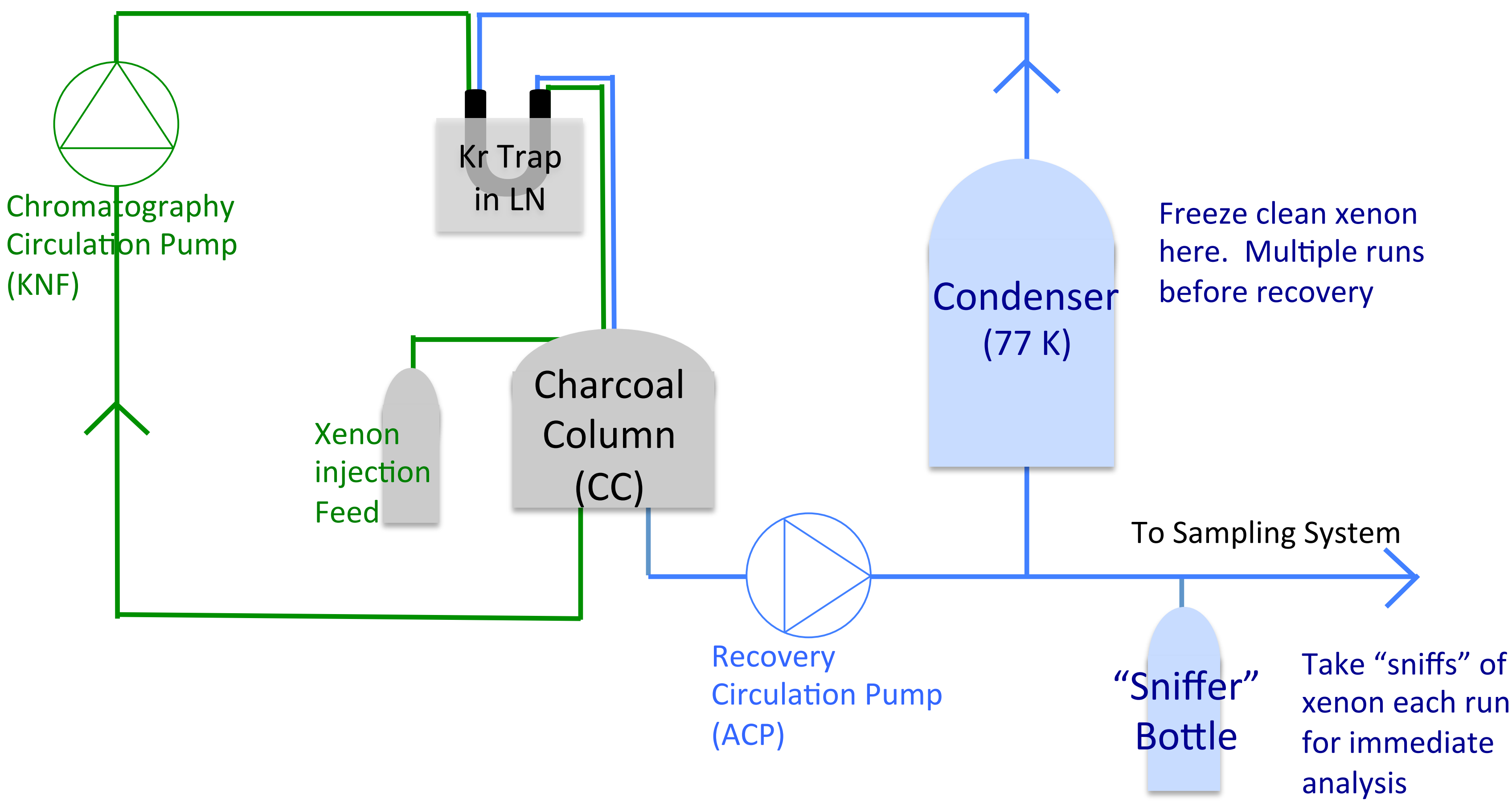
- Remove Kr via gas charcoal chromatography
  - Helium carrier gas
- Van der Waals bond between between noble gas and activated charcoal
  - Polarized atom attracted to it's image charge in conductive charcoal surface
  - Xenon: larger atom, more electrons, more polarizable
  - Faster flow rate of Kr through the charcoal





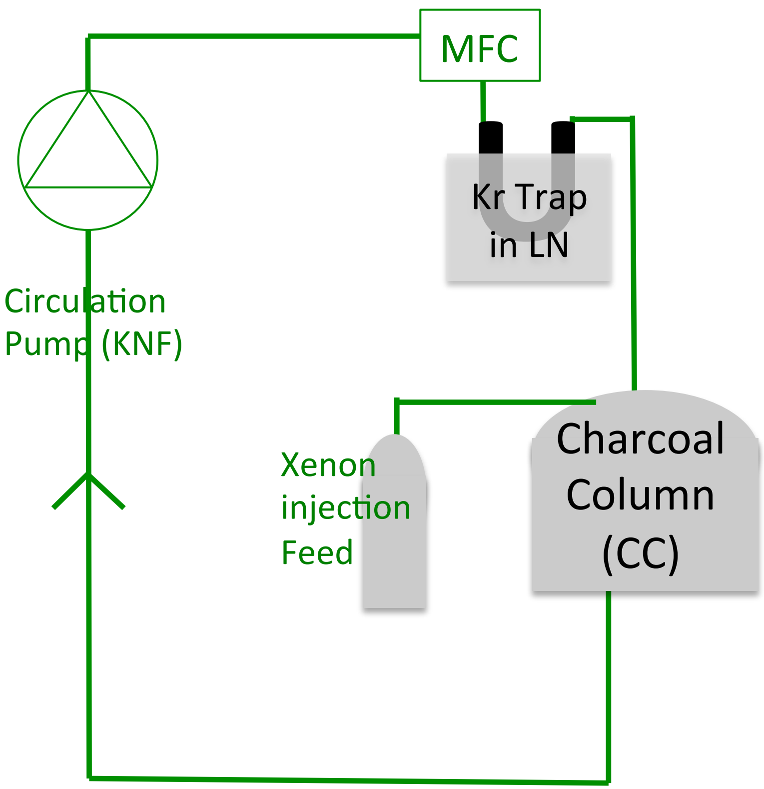
Kr Removal R&D System at SLAC

- Upgraded version of LUX Kr removal system (arxiv:1605.03844)
- Run through **Chromatography Loop** to trap Kr
- Then switch to **Recovery Loop** to recover purified xenon into condenser



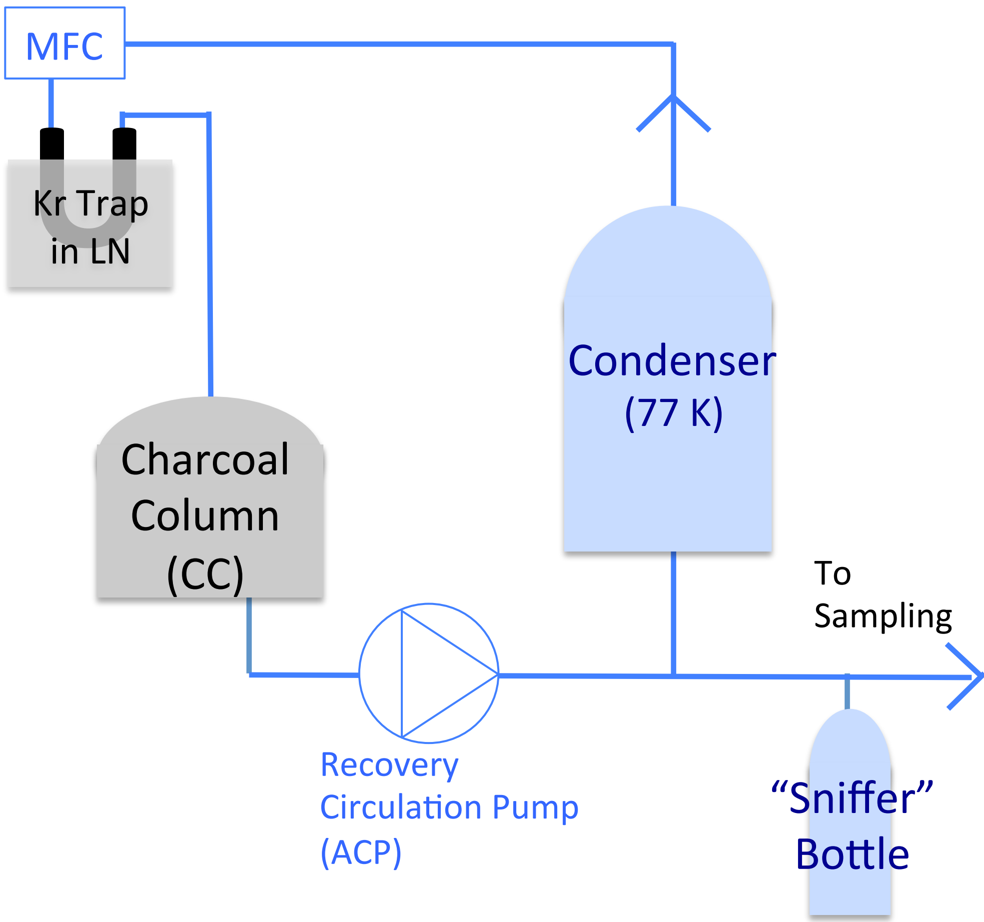
Chromatography Loop

- Charcoal Column
  - 60 kg activated charcoal
- Circulation Pump
  - KNF Diaphragm pump
- Kr Trap (in LN)
  - U-tube with activated charcoal
  - Only Helium can pass
  - Filters out Kr and any trace air or oil



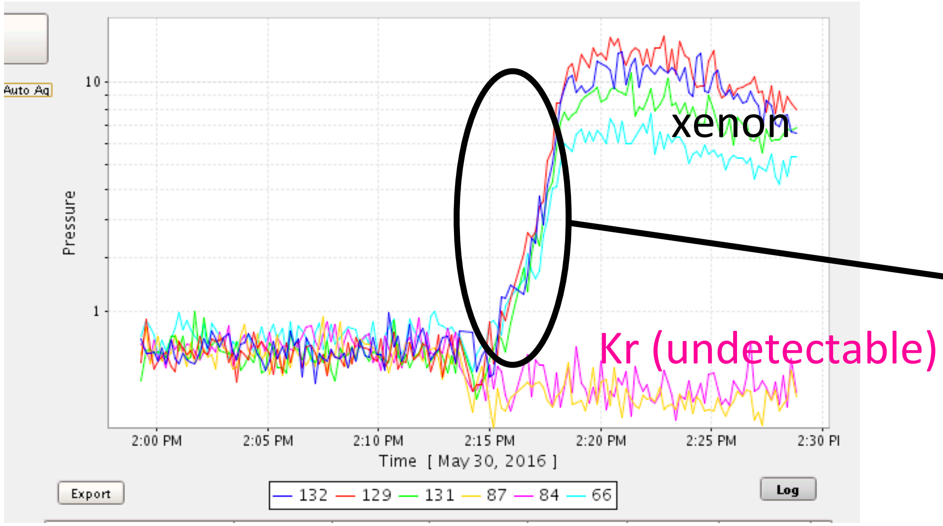
Recovery Loop

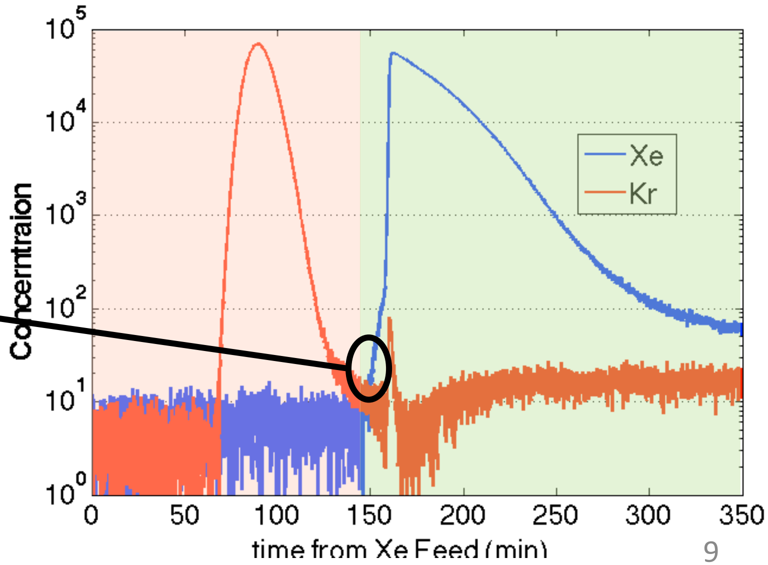
- Condenser
  - Freezes Xe on LN-cooled surfaces
  - Recover after every ~5 runs.
- ACP Pump
  - Recovery circulation pump
  - “Dry” roots blower
- Sniffer bottle (in LN)
  - Take small “sniffs” of He/Xe mixture
  - allows us to assay each run



Residual Gas Analyzer (RGA) & Cocktail runs

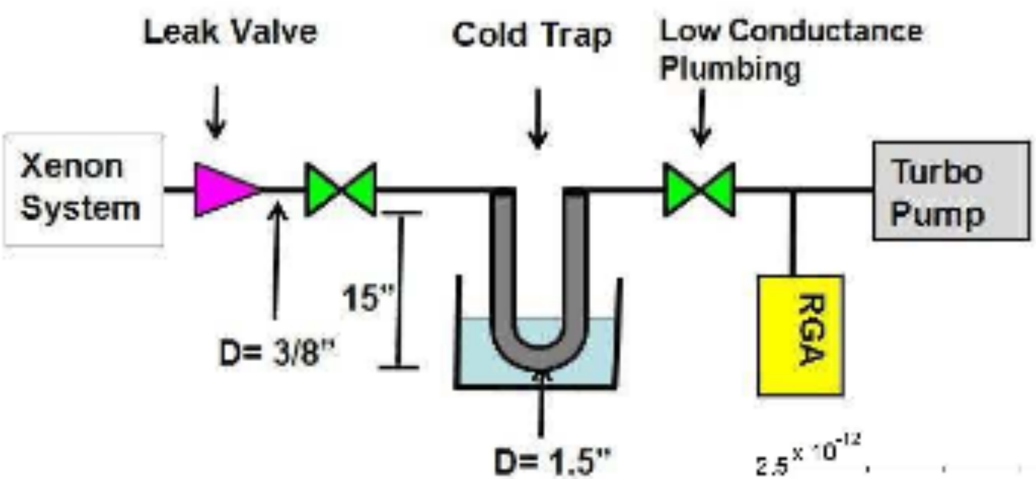
- RGA located after charcoal column,
  - Trigger switch to recovery once xenon is detected
  - Not sensitive to ppb level Kr
- Add Kr to Xenon to map chromatography

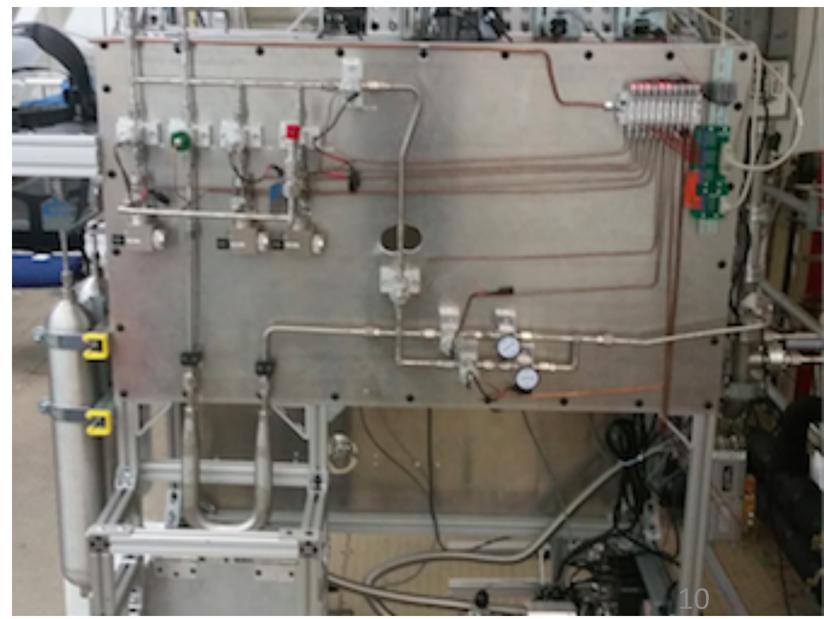




Distillation Assay System

- Cold-trap assisted RGA (arXiv:1103.2714)
- Developed by collaborators at UMD
- Sensitivity at the 0.005 parts per trillion level
- Will be moved to LZ for online purity monitoring





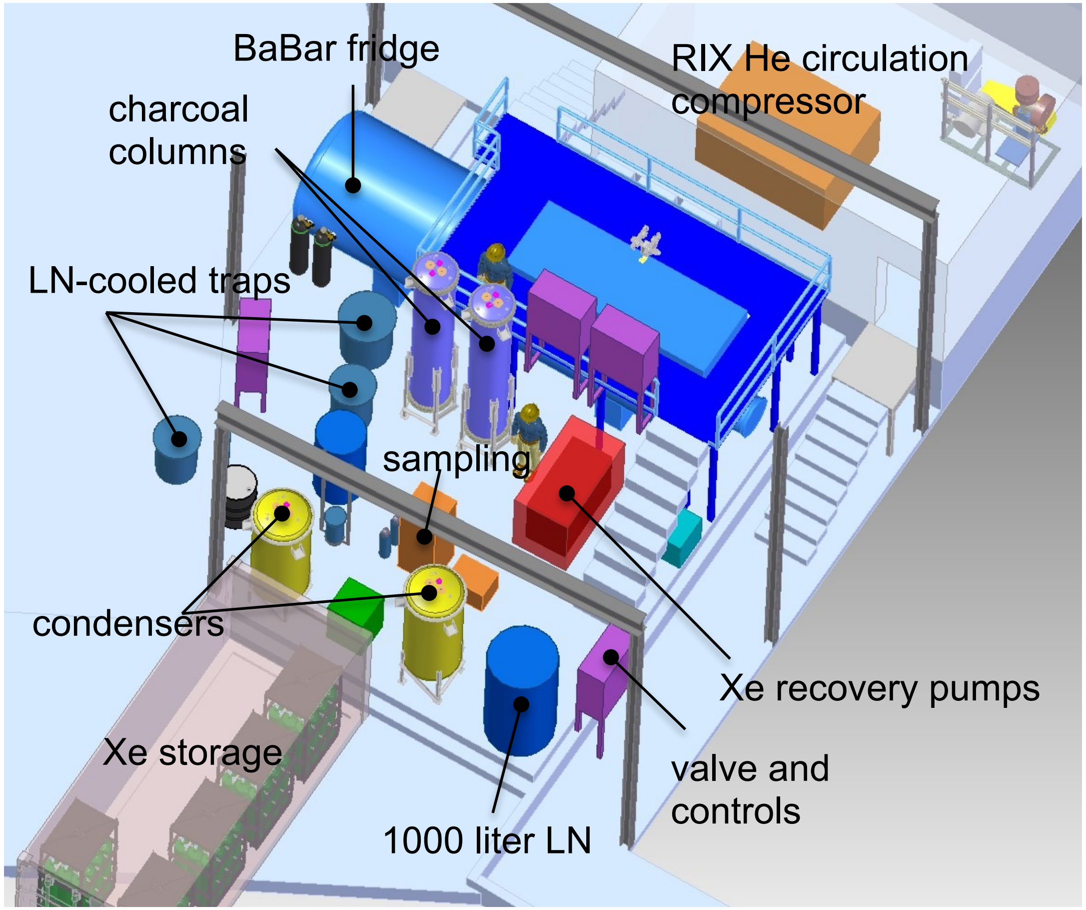
Results of Kr R&D

Commercial Xe:	1,000-100,000 ppt	
LUX:	3 ppt	
LZ Requirement:	0.3 ppt	
LZ Goal:	0.015 ppt	
R&D result	0.060 ppt	=> 1/2 solar neutrino background

- Main challenges were cross-contamination and trace impurities in UHP He
- Developed diagnostic tools such as a clean-xenon-backflow to systematically check isolated regions and components of the system
- Left with one more kr source in system which we could not fix
  - ‘Virtual leak’ from the gearbox of our recovery pump into the process space
  - Production system will use a different pump design without this failure mode!

Kr Removal Production System

- Process all xenon at SLAC
- ~1/2 of the LZ Xenon has already arrived and been assayed
- Scale up batch size by factor of 8 and overall processing rate by a factor of 20
  - 2 charcoal columns for continuous running

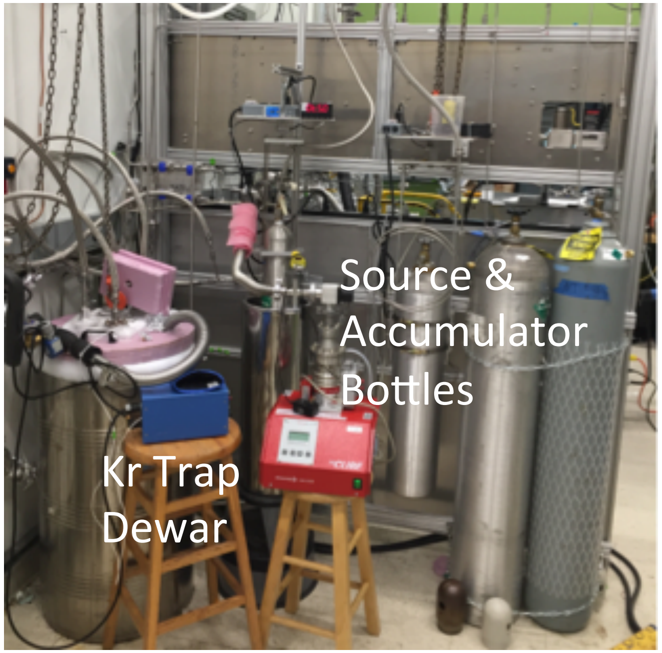


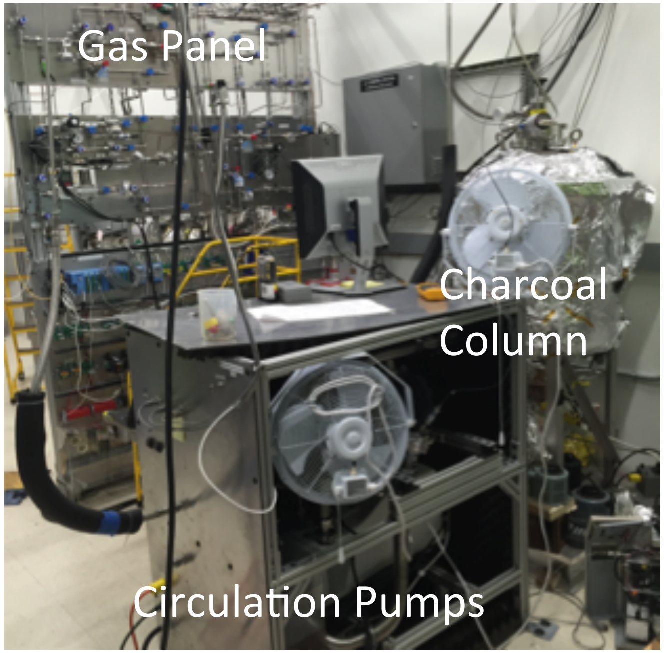
Conclusion

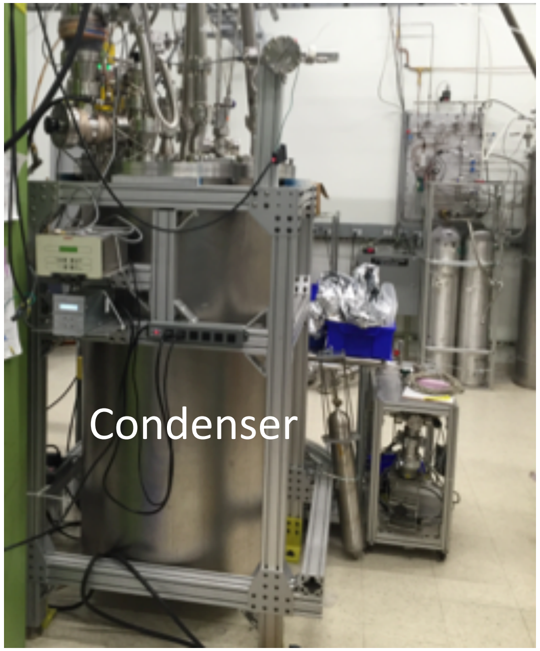
- Surpassed our Kr-85 requirement of 0.3 ppt by a factor of 5
- Expect to reach our ultimate goal of 0.015 ppt with the production system!
- Developed powerful diagnostic tools for use in production system
- Starting production system procurements, construct next year

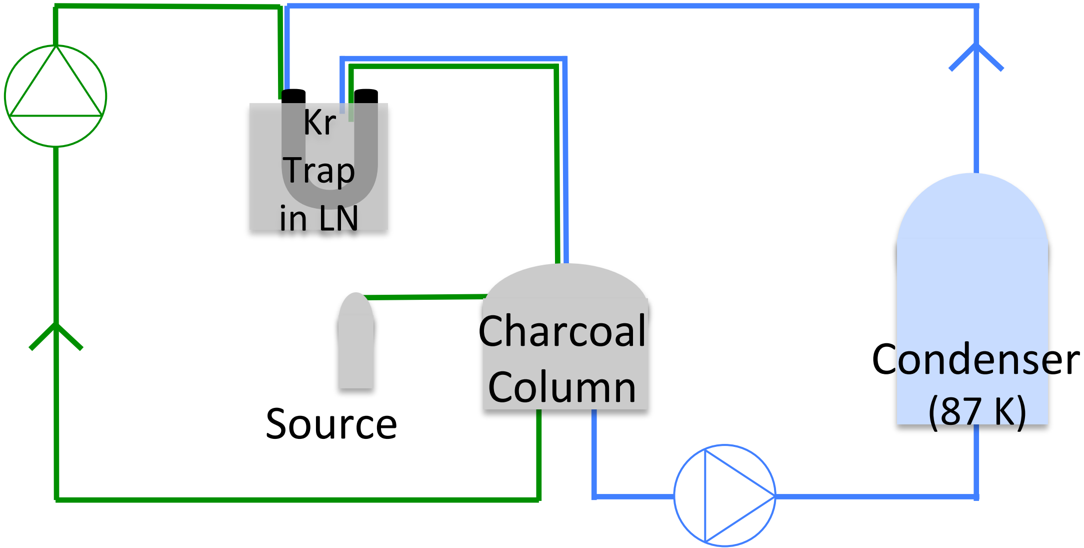
Backup

Kr Removal R&D System at SLAC



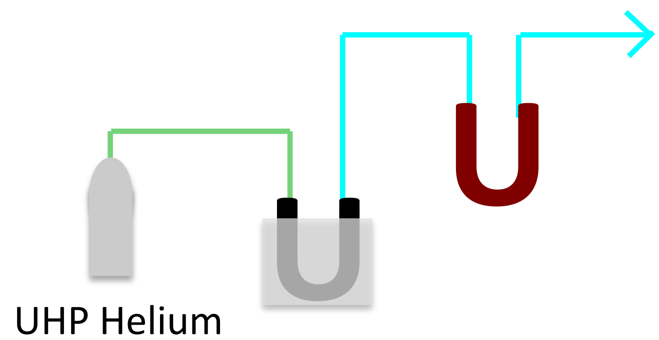




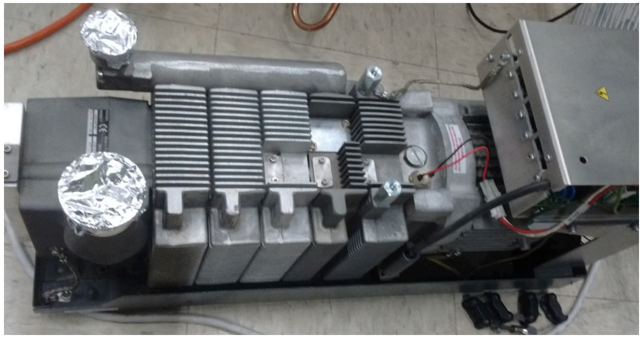


Lessons learned/Achievements

- Lowest concentration achieved was 0.06 ppt, a factor of 5 lower than our requirement
  - Not quite at 0.015 ppt, but likely to reach this in production system
- Discovered and removed sources of cross-contamination from the system
- Developed a method for assaying helium and learned that our UHP helium was not sufficient to clean the kr trap



- Hit limiting factor of R&D system: Recovery circulation pump had communication between gearbox space and process space, Kr outgassing from oil

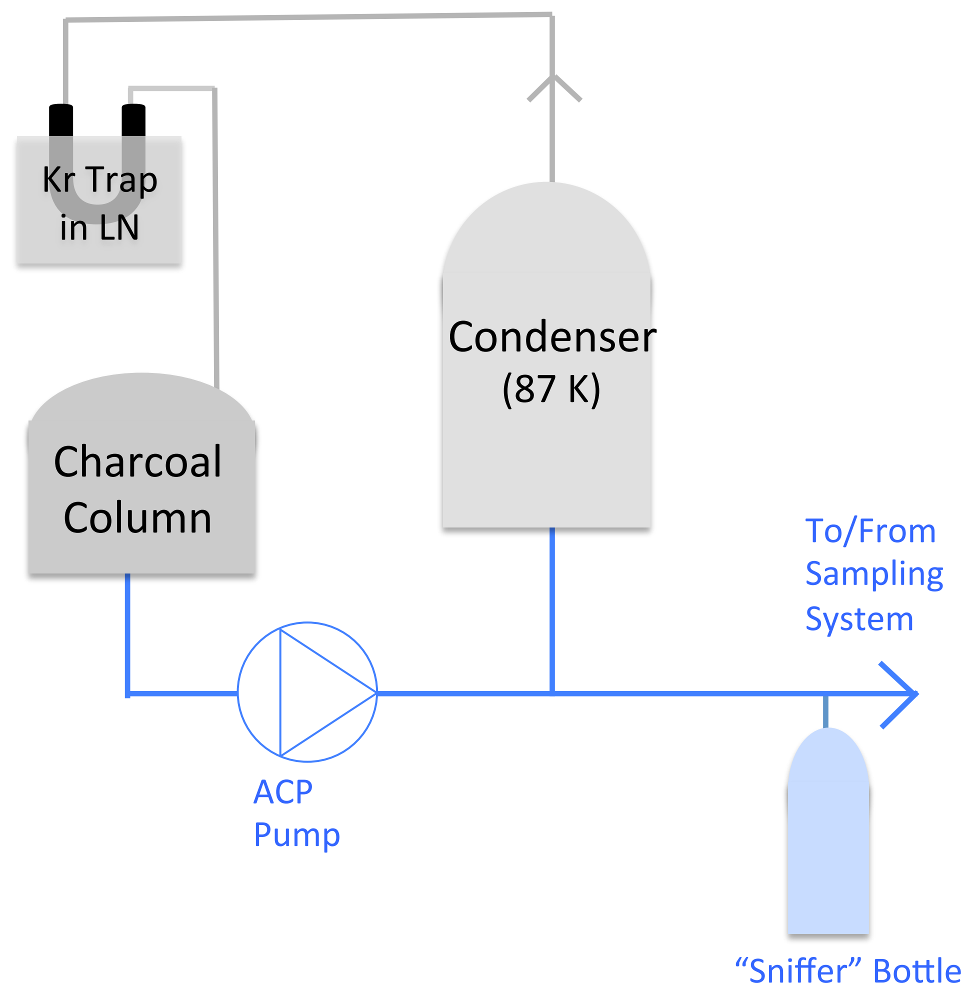


- All of this influences production system design!

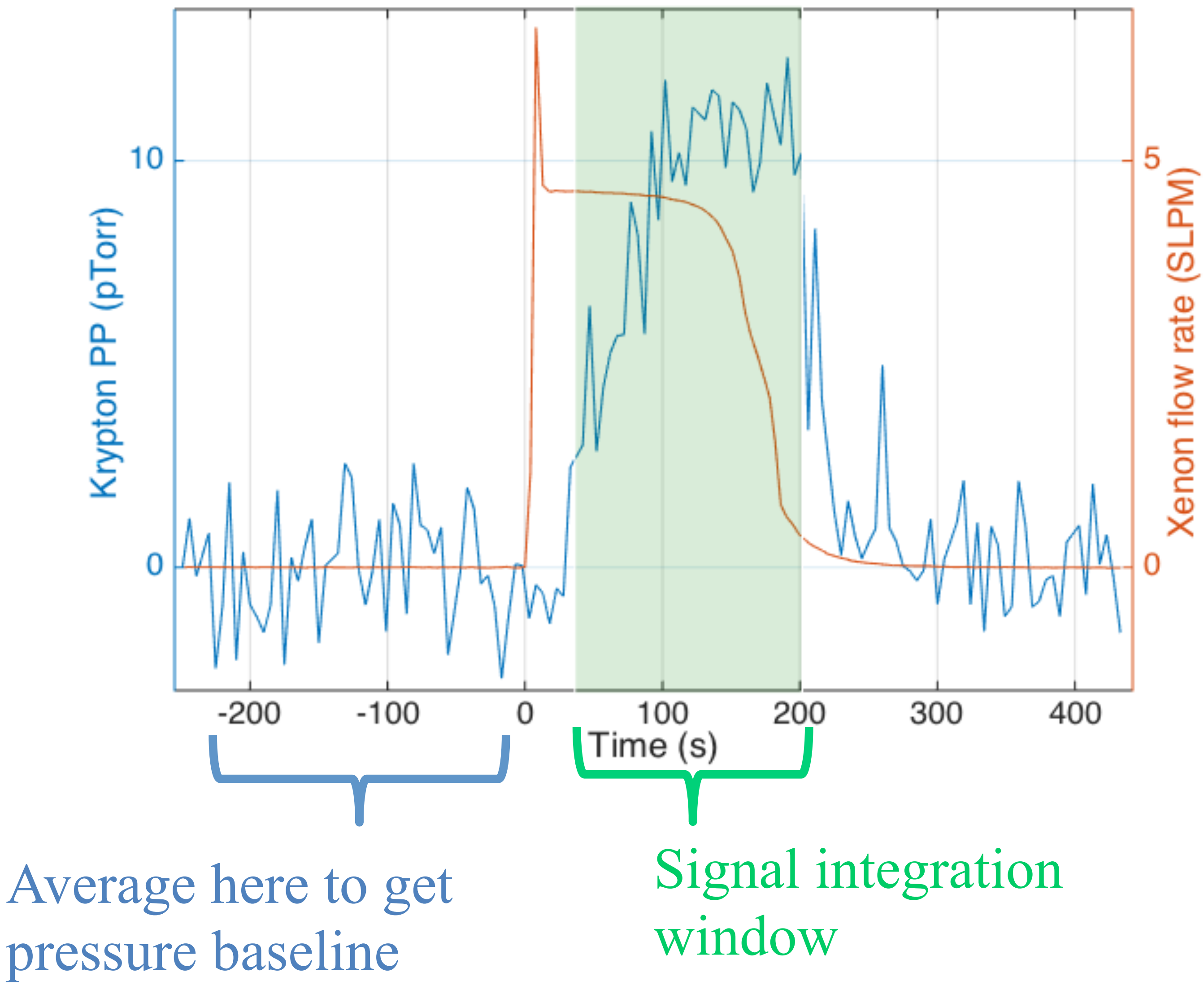
Diagnostics: Clean Xenon Backflow

Can make small amounts of <5 ppq Xenon with assay system

- Backflow small amount of xenon into test space
- Can diagnose contamination sources
  - led us to remove certain valves and filters from the recovery line
  - Led us to determine the limiting factor of the system

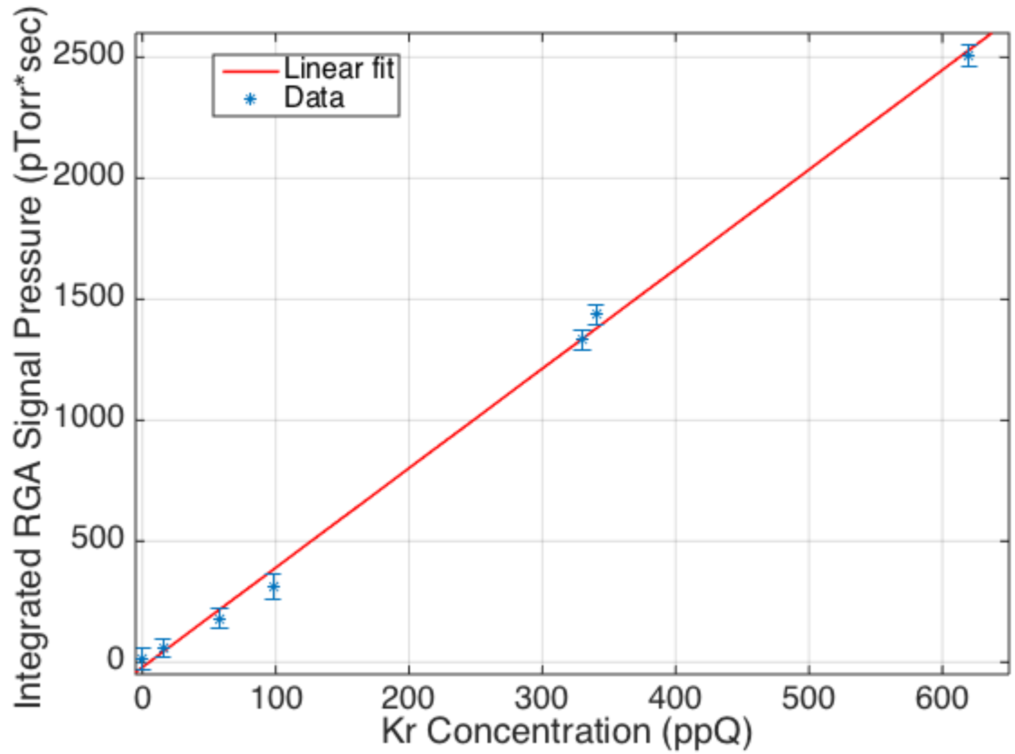


Distillation Assay System



Distillation Assay System Linearity

- Create stock calibration xenon with known Kr content
- Dilute with clean Xenon to map linearity
- Tune impedances of system and cold trap parameters to optimize signal and linearity



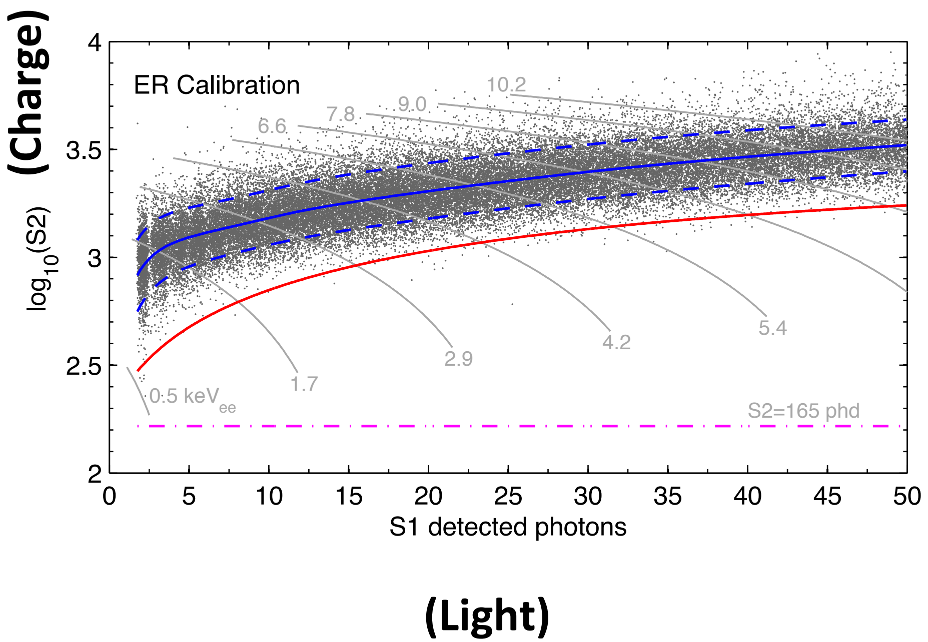
LZ System: scaling from LUX

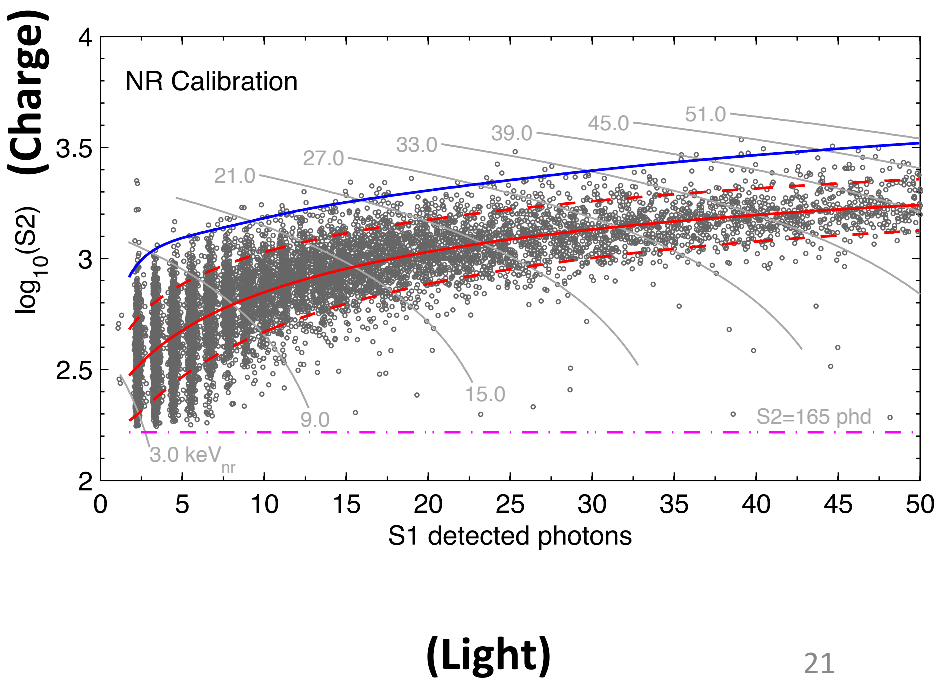
Scaling	LUX	LZ	
Column / slug size	2 kg Xe slug in 60 kg charcoal	16 kg Xe slug in 500 kg charcoal	Saturation: fix M
Chromatography	120 min: 100 LPM 50 SLPM @ 0.5 bar	120 min: 1000 LPM 500 SLPM @ 0.5 bar up to 2000 SLPM @ 2 bar	Transit time ~ M flow); higher pressure reduces diffusion
Recovery	180 min: 1500 LPM 15 SLPM He @ 10 mbar 120 SLPM Xe at peak	120 min: 25000 LPM 250 SLPM He @ 10 mbar	Match chromatography time; conservative scaling since 1.5 faster × 8 M volume flow, or 18000 LPM
Processing rate	2 kg / 5 hours 10 kg/day 50 kg/week, incl. storage	16 kg / 2 hrs 192 kg/day 20T / 120 days (85% uptime)	Continuous processing in LZ - no downtime for storage; 2 passes of 10 T

Background and Signal Calibrations

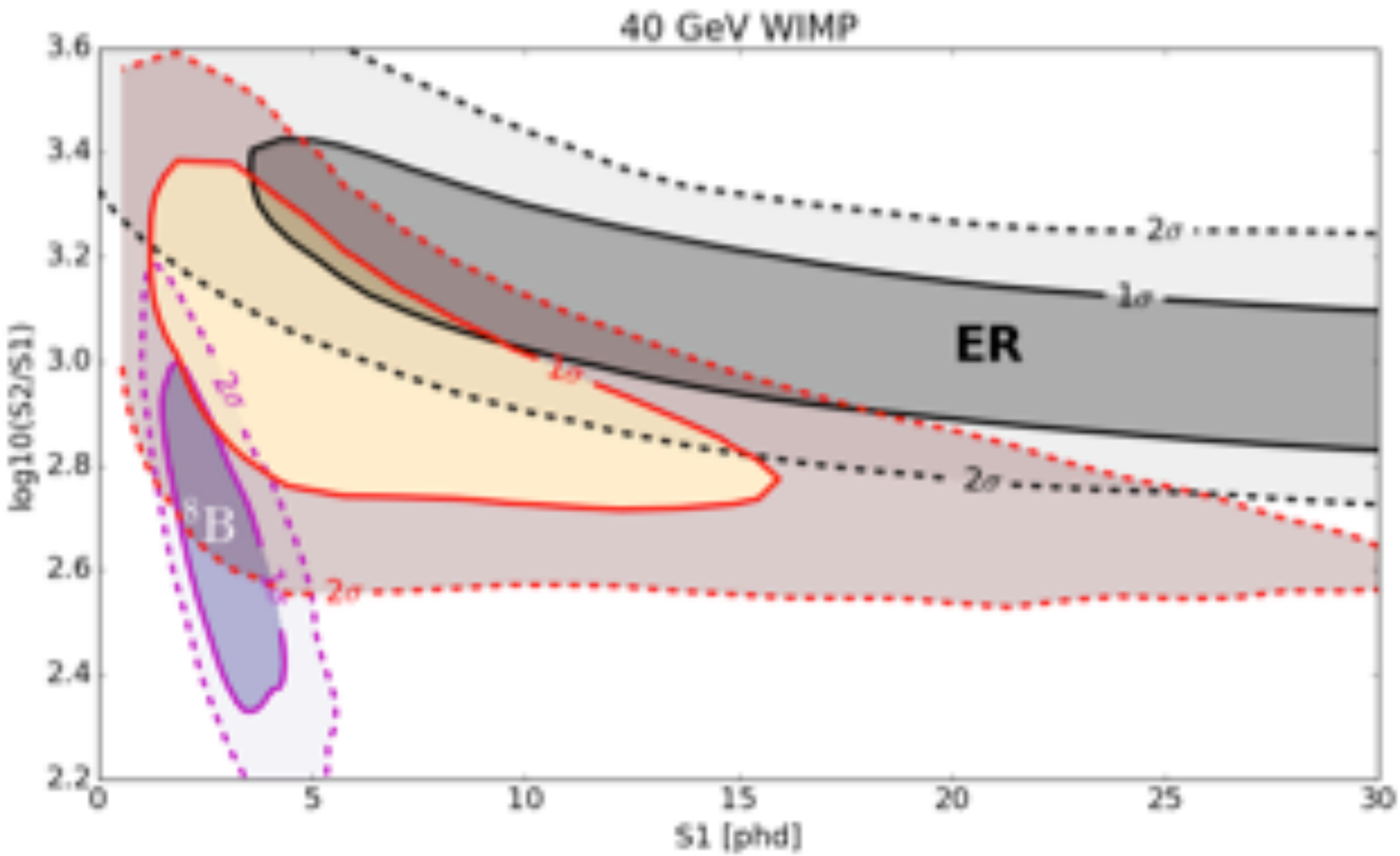
Background Events
- Electron Recoil (ER)
- Higher charge-to-light ratio
- Calibrate using high-statistics tritium dataset (LUX)

Signal Events (WIMP-like)
- Nuclear Recoils (NR)
- Lower charge-to-light ratio
- Calibrate using D-D neutrons (LUX)
  - *In-situ* nuclear recoil (NR) calibration





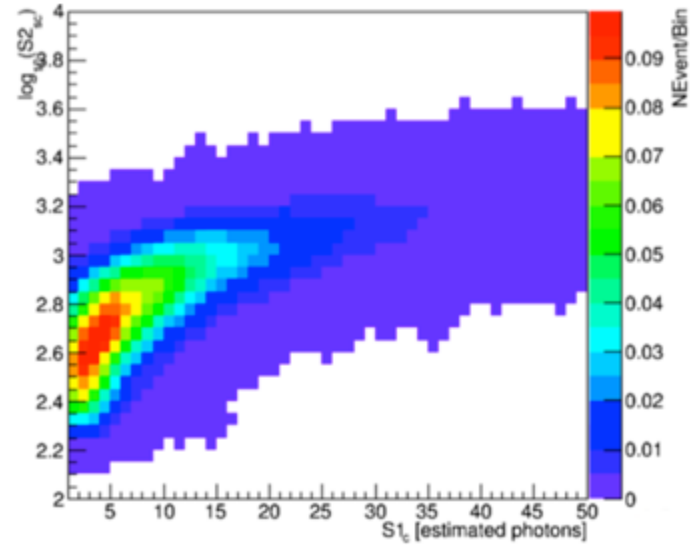
LZ Expected Signal from a 40 GeV WIMP with Expected Backgrounds



Profile Likelihood Ratio (PLR)

- Compares data to background distribution and signal distributions for different mass models
- Function of S1, S2, radius, and depth
- Fit for systematic parameters

i.e. Expected signal distribution for a 33 GeV WIMP



Lux data